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Pain Perception in Contact Sports

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Résumé

La douleur est une sensation universelle pour qui les termes descriptifs élicitent une reconnaissance immédiate. Les sensations de brûlure, de démangeaisons ou de tranchements aigus servent de signal d'alarme ayant pour but d'éviter des dommages corporels. Chez les athlètes, cette alerte est souvent ignorée afin d'atteindre l'excellence en performance. Dépendant du sport, le type de douleur ressenti peut varier. Dans le cas des athlètes d'endurance, la douleur survient naturellement dans le muscle due aux contractions répétées sur une longue période. Alternativement, les athlètes pratiquant un sport de contact doivent aussi anticiper de la douleur « mécanique » produite par des coups infligés par les adversaires. La différence dans la demande et la spécificité de chaque sport sont cependant rarement prises en considération dans les études sur la douleur chez les athlètes. Dans le cadre de ce mémoire de maitrise, une revue de portée a été réalisée pour mieux comprendre comment la perception de la douleur chez les athlètes de sports de contact est étudiée. Trois composantes ont été analysées : Les types de sports de contacts étudiés, les groupes auxquels ils sont comparés, et les méthodes utilisées pour induire expérimentalement la douleur. Onze études ont été retenues. Deux sous-catégories de sports de contact ont été identifiées. Les sports de combat ont plus souvent été inclus dans ces études que les sports d'équipe. Ces athlètes étaient comparés à des groupes composés de non-athlètes et d'athlètes de sports « non-contact ». Quatre méthodes d'induction expérimentale de la douleur ont été utilisés, soit, la pression mécanique, le froid, la chaleur et l'ischémie musculaire. Une justification des choix de méthode d'induction de la douleur ou types d'athlètes inclus dans le cas d'un groupe contrôle de sport non-contact est rarement fourni. Un vide existe dans la littérature quant à la comparaison de la perception de la douleur d'athlètes de sport de contact avec un groupe d'athlètes non-contact et une méthode d'induction expérimentale de la douleur choisi délibérément pour mieux refléter la réalité de la pratique sportive. Un protocole expérimental est proposé pour combler ce besoin.

Mots-clés : Douleur, athlètes, sport de contact, sport de combat, sport d'endurance

Abstract

Pain is a universal sensation whose descriptive terms elicit immediate recognition. The burning, itching, or sharp feelings serve as an alarm system meant to avoid bodily harm. In athletes, this warning is often ignored in the pursuit of performance. Depending on the sport, the type of pain encountered can vary. In the case of endurance athletes, pain occurs naturally within the muscle due to repeated contraction over a long period. Alternatively, athletes in contact sports must also anticipate mechanical pain caused by opponents. The difference in demand and the specificity of each sport are however very rarely taken into consideration when studying pain in athletes. A scoping review was used to better understand how pain perception in contact sport athletes is being studied. Three components were analysed: the types of contact sports being studied, the groups they are being compared to, and the methods used to experimentally induce and study pain. A total of 11 articles were included. Two subcategories of contact sport were identified. Combat sports were more often included in studies than team contact sport. These athletes were compared to both non-athletes and non-contact athletes. Four methods of experimental pain induction were used, namely, the pain pressure test, the cold pressor test, an ischemic pain protocol, and heat pain protocol. Justification was not always provided for either pain protocol selection or non-contact athletes selected as control group. A gap exists in the literature in comparing contact sport athletes' pain perception with a deliberately chosen athlete control group using a pain induction protocol meant to emulate a facet of pain experienced during exercise. A protocol proposal is included in the discussion to meet this demand.

Keywords: Pain, athletes, contact sport, combat sports, endurance sports

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List of abbreviations

CNS: Central Nervous System

DOMS: Delayed Onset Muscle Soreness

FPQ-III: Fear of Pain Questionnaire

MMA: Mixed Martial Arts

PCS: Pain Catastrophizing Scale

All we have to decide is what to do with the time that is given to us

Acknowledgements

I walked into the first day of my master's degree with a cut over my eye from a kick in the face and despite this was allowed to turn my interest in combat sport into an academic pursuit. For allowing me to follow my passion, I am incredibly grateful to my supervisor Benjamin Pageaux. I also owe thanks to my coaches and training partners who not only accepted me intellectualising our violent hobby, but quite literally kicked my butt when I needed it. This work would also not have been possible without my Ladies who pushed me, laughed, ranted, and fiercely supported me while taking on our projects in unprecedented times. I also could not fathom producing this document without Róisín, and Miró who put things into perspective by reminding me that their dinner time is more important than anything I have going on. Lastly, I want to thank my family for continued belief in me, for their support, their interest, their humour. Thank you for every phone call, every weekend getaway, every snarky comment in the group chat, and every "this article made me think of you." Thank you for being a safe place when the chaos got too loud.

Introduction

Pain is a universal sensation whose aim is to prevent harm. It can be described using a wide variety of terms such as burning, pulling, searing, stabbing, and sharpness (Melzack, 1973). Together, these interpretations of the feeling can inform individuals on the riskiness of a behaviour, the severity of an injury, or the progress of recovery. Athletes encounter all of these risks in the pursuit of performance (Pawlak, 2013).

While it is possible to generalise that most athletes encounter some sort of pain as part of their practice, the type of pain differs across disciplines and experience level. Endurance athletes such as marathon runners or long-distance cyclists have to endure the pain associated with repeated muscle contractions over a prolonged period of time (O'Connor, 2021). Contact sport, whether team sports or combat sports, must rather endure pain from contact with other players (Oxford University Press, n.d.). In the case of martial artists such as taekwondo, the main concern in terms of pain comes from blows exchanged with an opponent intent of causing harm (Ortenburger et al., 2016). Rugby athletes not only have to field tackle attempts, but will be subjected to the pain of repeated, long term contractions associated with sprints and distance running (Austin et al., 2011; Cunniffe et al., 2009; Yeomans et al., 2018). Contact sport athletes therefore must persist in a bout despite the unpredictability of pain.

Despite the variety of painful stimuli to which contact sport athletes are exposed, very little differentiation work has been done to understand how these types of pain are perceived by athletes during their practice. Furthermore, research is scarcely done to parse how people who practice contact sports may be more habituated to a certain type of pain when studying them, especially when compared to athletes having a different specialty. Initially, an experimental protocol aimed at using naturally occurring muscle pain during exercise was conceived to explore the difference in pain perception between contact sport athletes and endurance athletes. A summary of this experimental protocol was presented during the *Journée de la recherche de l'école de kinésiologie et sciences de l'activité physique* and is included in the perspectives section. The current COVID-19 public health crisis and its restrictions made data collection impossible, and so this thesis now focuses on the scoping review that was conducted to present an overview of the literature of pain perception in contact sports. This scoping review details which types of sports are being studied as well as which control, or comparison groups are chosen. It finally highlights the heterogeneity of methods used for inducing pain as well as which measurements are being taken for comparison.

This master's thesis will focus on pain perception in contact sport athletes. Exploring the ways in which pain is studied within this population will allow for a better understanding of which methodologies are best suited to study this topic and provide directions for future research. In the first chapter, a literature review will clarify how pain is studied, and how it relates to athletes. The second chapter will feature a scoping review aimed at mapping the existing literature on pain perception in contact sports. Finally, a third chapter will present the conclusion and perspectives as well as a summary of an experimental protocol that uses naturally occurring muscle pain during exercise to test differences in pain perception between contact sport athletes, endurance athletes, and normally active individuals. Determining the ways in which contact sport athletes may differ from other athletes in pain perception can help determine whether specific training can increase resistance. If this is in fact the case, recommendations can be made in terms of coaching to improve athlete performance.

Chapter 1 – Literature Review

1. What is pain? A biopsychological approach

Defining pain

Pain is a multidimensional experience encompassing more than simple biological processes (Moayedi & Davis, 2013). Historically, several theoretical frameworks have competed in trying to develop an inclusive and complete model for pain (Moayedi & Davis, 2013). As of 2020, the International Association for the Study of Pain (IASP) has revised its previous 1986 definition of pain, but the gist remains the same: “An unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage” (Raja et al., 2020). The definition is supplemented with several key notes to provide context, specifically, the fact that “pain is always a personal experience that is influenced to varying degrees by biological, psychological, and social factors” (Raja et al., 2020). The definition’s phrasing remains vague, but it allows for individuals to express what they are feeling using increasingly precise terms such as “burning” or “pinching” whether those terms are literal or not. While the definition maintains that pain is always a subjective experience influenced by emotional, biological, and social factors, the phrasing is more inclusive for populations unable to describe their experience verbally. The ability to describe pain can therefore be explored as a particularity of the feeling and highlights its highly subjective nature. The biopsychosocial approach is crucial since the emotional, biological, and social factors cannot be separated one from the other. This is essential when studying pain in sport since athletes’ performances rely on more than pure physical capacity. Mentality and sport culture must be considered to fully understand pain perception[1] and how it contributes to athletic performance.

Neurobiology of pain

[1] According to Cabanac (1995), sensation is the biological process allowing for a stimulus to be inputted into the central nervous system. In the context of pain, this would be nociception, defined in the following paragraph. Perception then reflects the higher order processing (emotional, contextual, etc.) of the input in the CNS.

The International Association for the Study of Pain (IASP) offers its own definition of nociception as such: “The neural process of encoding noxious stimuli, with the added note, consequences of encoding may be autonomic (e. g. elevated blood pressure) or behavioral (motor withdrawal reflex or more complex nocifensive behavior). Pain sensation is not necessarily implied.” (IASP) Much like other sensory signals, specialised fibers, known as nociceptors, transmit an afferent message that must then be interpreted by the cortex and blended with contextual and autobiographical factors (O'Connor & Cook, 1999). These fibers send axons from the periphery to the dorsal root ganglia of the central nervous system [CNS (Purves, 2001)]. The noxious stimulus is interpreted as such by the CNS if it is currently, or potentially, causing tissue damage (Sneddon, 2018). The cognitive contribution cannot be separated from the biological when studying pain since “pain cannot be inferred solely from activity in sensory neurons” (Raja et al., 2020). When in working order, sensory neurons from the periphery are responsible for producing information interpretable by the CNS that then translates it into the pain alarm system.

There are two types of nerve fibers known to be the carriers of painful stimuli: Type III and Type IV (O'Connor & Cook, 1999). These fibers both have free nerve endings, and differ slightly depending on their function such as detecting mechanical pressure, metabolic changes, or exposure to harmful temperatures (Sneddon, 2018). The III fibers, also known as Aδ, are equipped with a light myelin sheath which allows for relatively faster information transmission (Purves, 2001). Type IV, or C fibers as they are also known, are unmyelinated and thus transmit information slower than type III fibers since myelination insulates the fiber and improves transmission speed (Figure 1) (Purves, 2001).

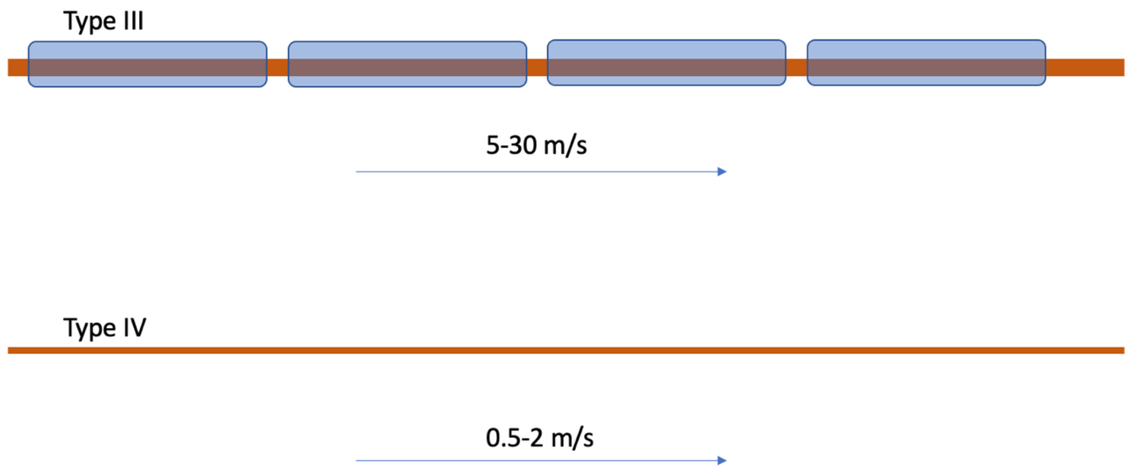

Figure 1: Transmission speed of myelinated type III fibers and unmyelinated type IV fibers, spaces between blue rectangles representing myelin stand in for the nodes of Ranvier (O'Connor & Cook, 1999)

In the skin, both types of fibers are involved in transmission of nociception. Type III fibers come in two major categories: mechanoreceptors and mechanothermal receptors (Purves, 2001). Mechanoreceptors respond to noxious pressure while mechanothermal receptors respond to both alarming thermal stimulus and mechanical stimuli (Bajwa et al., 2003). The type IV fibers of the skin are polymodal, they react to mechanical, thermal and chemical stimuli (Sneddon, 2018). Interestingly, type III and IV fibers are also present in the muscle to allow for detection of damage on that level.

When stimulated in the muscle, both types of fibers produce dull, aching sensations (O'Connor & Cook, 1999). Several biochemicals are known to activate nociceptors at the muscular level. Bradykinin, potassium, serotonin, and histamine will increase the firing rate of muscular type IV fibers making them key factors in naturally occurring muscle pain during exercise as they are synthesised and released in response to tissue damage (O'Connor & Cook, 1999). These substances can also sensitise type III fibers without directly stimulating them (O'Connor & Cook, 1999). Similarly, substances such as hydrogen ions, inorganic phosphate, and prostaglandins will sensitise nociceptors, decreasing their overall activation threshold (Ducrocq & Kaufman, 2020; O'Connor & Cook, 1999). The free nerve endings of both type III and IV fibers are located in the connective tissue as well as along arterioles (O'Connor & Cook, 1999). This makes them perfectly located to transmit information on damaged skeletal muscles whether that means physically compromised or simply active (O'Connor & Cook, 1999). This is especially useful since muscle damage produces the aforementioned substances known to either sensitise or activate afferent pain signals (O'Connor & Cook, 1999). When it comes to naturally occurring muscle pain during exercise, a subset of IV fibers might be the culprits of the familiar feeling since they have a preferred response to muscle contraction when blood flow is limited (O'Connor & Cook, 1999). This feeling can reliably be produced using cycle ergometry and is consistently identified as painful (Cook et al., 1997; O'Connor & Cook, 2001). On top of basic neurochemical reactions, individual differences, and differences across sensitization through athletic training could contribute to an overall varied experience of pain. The type of nociceptor signals being fired during sport may in fact vary depending on the demands of practice. Pain that arises in the muscle during exercise is not widely studied, but is plausibly linked to the release of metabolites into muscles damaged by repeated contraction as well as the actual damage (Cook et al., 1997).

Psychological aspects of pain

Pain is a highly subjective experience that cannot be understood without the context of an individual’s higher cognitive processing (Raja et al., 2020). Several psychological moderators serve to inform and colour the resulting feeling for an individual (Auvray et al., 2010; Gorczyca et al., 2013). Reminding that pain is meant to be an alarm system to prevent harm, these context clues can therefore be useful to dampen or amplify the message. Melzack and Wall’s Gate Control Theory reflects this reality (Melzack, 1999). The theory is regarded as a preliminary model for pain perception being the result of multiple interacting factors (Ropero Peláez & Taniguchi, 2016). The gate in question is a metaphor for a modulator that allows for more or less of a signal to be felt by the individual in pain (Melzack, 1973). In short, it aimed to explain why rubbing an injured area produces relief (Melzack, 1973). The concept was taken further and theorised that psychological factors such as pain anxiety contribute early on to the overall sensation (Melzack, 1973). While the model has been widely debated since the 70s, the idea remains that pain and its resulting feeling can be modified by factors other than neurobiological pathways.

One such modifier may be attributed to an athlete's coping strategy (Johnson et al., 2012). The ability to ignore pain in order to adequately engage in daily tasks as well as the belief that pain can be controlled are two such traits (Cano et al., 2006). Conversely, an amplified apprehension towards pain can worsen the experience (Sullivan et al., 2001). Differences in self-efficacy, the belief in one's own self, capacities, and ability to accomplish a task (Chen et al., 2001), while perhaps present in non-active individuals, contributes significantly to a marathon runner's increased pain tolerance (Johnson et al., 2012). Extreme endurance athletes also show a decreased fear of pain (Geva & Defrin, 2013). These traits can alter an athlete's willingness to play through pain. In fact, the more an athlete can ignore pain, or at least downplay it, the more likely they are to play through pain and maintain their engagement (Deroche et al., 2011). When studying contact sport athletes, it is crucial to keep in mind that certain traits can contribute to their ability to play through pain and that such types of sport might simply attract that type of person. This predisposition does not, however, tell the whole story and the capacity to withstand the demands of sports such as rugby or muay thai can be learned.

Habituation to pain can also occur, resulting in a "diminished effectiveness of a stimulus in eliciting a response" (APA dictionary of Psychology, n.d.) While some may not benefit from a naturally higher pain tolerance or ability to cope, they can still learn to ignore pain signals over time if those signals were repeatedly shown to be safe (De Paepe et al., 2019). Habituation to pain occurs in higher level processing when a cognitive representation of a repeated stimulus is built (De Paepe et al., 2019). This internal model is then compared to an actual stimulus, and if they match, the feeling is attenuated (De Paepe et al., 2019). Brain imagery confirms that exposure to a repetitive, consistent pain stimulus actually reflects in the brain by a decrease in pain areas such as the somatosensory cortex and anterior cingulate cortex (Bingel et al., 2007). This is especially interesting when it comes to contact sports and the possibility that people who engage in such activities are somehow naturally better at tolerating pain from the start. A longitudinal study that examined those who began contact sports and stuck to them showed that over time, pain tolerance increased, and the "bothersomeness" of pain decreased (Thornton et al., 2017). They concluded that coping skills were developed over time to deal with the specific demands of the sport and therefore "having a low pain tolerance should not prevent athletes from taking part in contact sports" (Thornton et al., 2017)

2. Studying pain

Methods – Pain measurements

Pain is a multifaceted, subjective experience and differs depending on the causal stimulus. Not all pain is created equal. For this reason, several methods of pain testing exist. A researcher's choice can depend on what tools are on hand or the desire to test a specific parameter. Several measurements can be taken and therefore must be defined. In O'Connor and Cook (1999) two reference measurements are taken that help frame experimental pain. **Pain threshold** is defined as "the minimum intensity of a stimulus that is perceived as painful" (IASP terminology). This must be self-reported by the participant and can be registered by, for example, a verbal cue (e.g. Leznicka et al., 2016), or the press of a button (Focht et al., 2000). Additionally, researchers can choose to identify the point of **pain tolerance**. This is defined as "the maximum intensity of a pain-producing stimulus that a subject is willing to accept in a given situation" (IASP terminology). Most often, the participant can simply remove themselves from the pain apparatus (e.g., Leznicka et al., 2016). Alternatively, this point can be signaled verbally (e.g., Leznicka et al., 2017). In all cases, experimental protocol states a maximum attainable setting for pain induction. Whether mechanical pressure or cold, an upper limit is predefined, though often not shared with participants, and is meant to avoid damage to the person (e.g., Leznicka et al., 2017).

A variety of tools can be used to quantify **pain intensity** during an experimental procedure. **The Visual Analog Scale** (figure 2) relies on a horizontal line anchored with verbal cues on each end (Haefeli & Elfering, 2006). The line starts at "no pain" and ends on "pain as bad as it could be." (Haefeli & Elfering, 2006) The patient is asked to draw an intersecting vertical line that corresponds with their pain intensity (Haefeli & Elfering, 2006). This was deemed more accurate that a horizontal line with a 1-10 numerical gradation since a person's experience with the scale influenced its outcomes (Scott & Huskisson, 1976). The scale can be used both on paper and digitally with no effect (Jamison et al., 2002). Another method of measuring pain intensity is a simple **Numerical Rating Scale** (figure 3), where ten numbers are offered up to choice along with verbal anchors (Haefeli & Elfering, 2006). On this scale, a 0 would represent "no pain at all" and 10 would be the "worst pain imaginable" (Haefeli & Elfering, 2006). In any studies involving athletes in action, a verbal scale would be the most useful since it does not require a participant to stop to share their assessment or their pain intensity.

Figure 2: Visual Analog Scale (Haefeli & Elfering, 2006)

Figure 3: Numerical Rating Scale (Haefeli & Elfering, 2006)

Methods – Inducing pain

When inducing pain in lab settings, many options are available to researchers. As mentioned, not all pain is the same. For example, pain induced by mechanical pressure activates a different afferent pathway than pain induced by prolonged cold (Janal et al., 1994b). The choice of methodology used to induce pain in a laboratory setting can be due to the need to activate a particular pathway or simply because of apparatus availability (Janal et al., 1994b). Depending on the study, a specific test may be chosen to approximate a certain pain condition.

One of these methods, the **Pain Pressure Test** or **pressure algometry** aims to cause mechanical pain through tissue compression (Chesterton et al., 2007). A device called an algometer is placed on a chosen body part, often an extremity, and pressure slowly increases (Kinser et al., 2009). Depending on the area being compressed and the pressure applied, this technique can aim to stimulate a cutaneous pathway or a combined cutaneous and muscular pathway. The participant can be asked to identify the pain threshold, the point of weak pain, and the point of moderate pain, and pain tolerance to name options (Dissanayaka et al., 2018). Devices have an upper limit that prevents causing lasting damage to the participant (Dissanayaka et al., 2018). The devices may vary, but whether digital or analogue, results remain valid (Castien et al., 2021). Mechanical pain through pressure can be useful in studying contact sports because of the approximate correspondence to the type of pain felt when in interacting with opponents.

Pain can also be caused through thermal means (Janal et al., 1994b). Both heat and cold can activate nociceptive afferent pathways (Janal et al., 1994b). An often-used setup involves a tub of cold water kept at a standardised, near freezing, constant temperature whether through a simple ice bath (e.g. Janal et al., 1994b) or a tank equipped with circulation system (e.g. Raudenbush et al., 2012). The **Cold Pressor Test** asks participants to submerge a limb (hand, foot, etc.) and signal the point at which the cold becomes painful, i.e. the pain threshold (Mitchell et al., 2004). They can also be asked to remove their limb when the pain becomes unbearable to establish pain tolerance (e.g. Thornton et al., 2017). An upper time limit is always enforced to prevent injury to the participant, though they are not always made aware of it (Thornton et al., 2017). On the other end of the spectrum, heat pain can also be chosen as a method of pain induction (Janal et al., 1994b). In one setup, a focused light beam shines through safety glass onto the participant's skin (Kostek et al., 2016). A device called a thermode can also be used to produce heat through contact between its copper surface and skin (Dyck et al., 1996; Wong et al., 2010). While neither of these pain profiles are intuitively typical of sport practice, they may be useful as a non-habituated comparison point when studying pain perception in different kinds of athletes.

Ischaemic pain is generally produced using the submaximal effort tourniquet technique (Janal et al., 1994b). Venous blood in the targeted limb is drained by lifting it (Reinert et al., 2000). A cuff is then fixed to the medial portion of the limb and inflated to the point of throttling blood flow, but minimising nerve compression (Reinert et al., 2000). Muscle contractions are then performed using the portion of the limb lateral to the cuff such as squeezing a hand dynamometer ball (Reinert et al., 2000). The cuff can be released quickly once pain tolerance is reached (Reinert et al., 2000). Naturally, this method of pain induction also involves pressure pain from the constricting cuff, but the two can be discriminated from one another (Pertovaara et al., 1984). The resulting pain is proposed to be induced by an accumulation of trapped metabolites resulting from muscle contraction such as potassium, inorganic phosphate, or adenosine which as previously discussed can either sensitise or activate nociceptors (Graven-Nielsen & Arendt-Nielsen, 2003). While mechanical pain habituation might be speculated on in contact sport athletes, a similar theory of habituation of noxious metabolites may be attributed to endurance athletes.

Similar to methods relying on naturally occurring painful metabolites in the muscle to produce pain, **chemical induction** of muscle pain is possible through injection of noxious substances (Graven-Nielsen & Arendt-Nielsen, 2003). Most used is the intramuscular injection of hypertonic saline which produces a similar feeling to exercise induced muscle pain (Graven-Nielsen & Arendt-Nielsen, 2003; Smith et al., 2021). Normally naturally occurring substances such as bradykinin, serotonin and prostaglandin can also be injected into the muscle to produce a similar algesic response to the one produced during intense exercise (Graven-Nielsen & Arendt-Nielsen, 2003). These methods are effective at producing muscle pain, but are slightly more invasive than using exercise to produce a similar sensation (Graven-Nielsen & Arendt-Nielsen, 2003). However, when comparing athletes this method may lack the addition of important context clues present in play that are approximated more closely when using a cycling or treadmill protocol.

Producing a type of pain to which few are habituated can be a challenge, but painful **electric shock** can readily be induced in a laboratory setting (Graven-Nielsen & Arendt-Nielsen, 2003). This method can allow for muscular stimulation as well as cutaneous stimulation, and comparison between the two (Graven-Nielsen & Arendt-Nielsen, 2003). An electrode can be placed either on the skin or intramuscularly (Graven-Nielsen & Arendt-Nielsen, 2003), making it a more invasive choice for pain induction.

Ischemic pain protocols are executed to produce near immediate pain upon muscle contraction, but it is also possible to use repeated muscle contraction to produce future muscle pain. The phenomenon known as **Delayed Onset Muscle Soreness**, or DOMS, can also be quantified in reaction to an exercise protocol (Black et al., 2016). This persistent pain generally appears in the first 24 hours following strenuous or novel exercise and can last up to seven days, peaking around the 48 hour mark (Armstrong, 1984). DOMS generally result from muscle damage created by a physical activity involving eccentric contraction (Harper et al., 2021). Many protocols are available for producing this pain. For instance, five minutes of eccentric cycling at 50% of an individual’s maximum power can predictably produce the sensation (Harper et al., 2021). Though the mechanism of DOMS is not completely understood, it is a valid and predictable source of pain. Realistically, most athletes have experience with this type of pain and therefore a good candidate for a comparison of muscle pain across sport disciplines.

When it comes to studying pain in athletes, however, several of these methods may not be entirely appropriate. Athletes are subjected to endogenous, **naturally occurring muscle pain** (Cook et al., 1997). This pain can be perceived during rigorous endurance training or simply repeated movement. Very few instances of research using exercise as a painful stimulus exist despite cycle ergometry being a reliable method of producing this type of pain (Cook et al., 1997; O'Connor, 2021). As mentioned, an experimental protocol was written using this method of pain testing to explore exercise induced muscle pain in contact sport athletes as compared to endurance athletes (Conclusion and perspectives).

Methods – Pain questionnaires

In addition to these, researchers may choose to ask participants to fill out one or several questionnaires. Of these, the **Pain Catastrophising Scale** (PCS), aims to qualify the previously mentioned idiosyncratic views on pain (Sullivan et al., 2001). The scale is widely used and accurately reflects how certain individuals' expectations of pain can affect their subjective experience of it (Sullivan et al., 2001). In fact, in a study examining pain outcomes in athletes when compared to non-athletes, the questionnaire was found to be a predictor of pain outcomes (Sullivan et al., 2000). Put simply, high levels of pain catastrophising then leads more intense perception of pain (Fischerauer et al., 2018).

The **Fear of Pain Questionnaire** (FPQ-III) is also widely used to qualify an individual's hesitancy in the face of pain (Asmundson et al., 2008). In fact, fear or apprehension can lead to a heightened subjective painful experience (Patanwala et al., 2019). In simple terms, pain can be felt more vividly or more intensely if there is anxiety surrounding it. This questionnaire, in addition to pain catastrophising, can contribute to creating a more complete portrait of pain perception by adding psychological insight into the athletes being studied. As stated in Raudenbush et al. (2012), these predispositions in the face of pain can be modified with exposure.

Another such questionnaire is the **McGill Pain Questionnaire** (MPQ) which allows participants to describe their pain using an organised list of terms as well as body diagrams (Melzack, 1975). While it has many uses, it is another interesting tool for peering into the subjective experience of pain. If, for instance, a research subject selects the term “burning” to describe their muscle pain after cycling, it gives insight into the intensity of the stimulus. Another person might, on the other hand, describe a similar feeling using a term such as “aching” or “pulling” therefore allowing us to surmise that subjective experience is different despite taking part in the same activity. In conjunction with a visual analog scale, it can also serve as a benchmark for evaluating pain over time in, for instance, injury recovery.

This is not an exhaustive list of pain-related questionnaires but serves to highlight options available when considering a pain protocol. The psychological component of pain perception should not be ignored as it is a crucial clue into the profiles of people who take up and invest themselves in contact sport.

3. Pain in Sport

As mentioned, pain is a natural consequence of intense sport training whether it be naturally occurring in the muscle (O'Connor, 2021) or due to contact with an opponent. The relationship between pain and physical activity extends beyond the acute production The consistent temporary effect of pain reduction following physical exercise has been widely studied (Kodesh & Weissman-Fogel, 2014). In fact, pressure analgesia can be felt five minutes following a simple 10-minute bout of aerobic exercise if done at an intensity over 50% of a person’s V̇o2max (Hoffman et al., 2004). It then follows that long term practice of exercise may change how active individuals modulate pain (Flood, Waddington, & Cathcart, 2017; Flood, Waddington, Keegan, et al., 2017; Flood, Waddington, Thompson, et al., 2017). Athletes who are able to push through the pain, then, can count on that adaptation to modulate to impact their overall performance (Flood, Waddington, Keegan, et al., 2017).

Athletes are not all the same and depending on their chosen sport, they are subjected to vastly different requirements and experiences. Different categories of sport exist along loose lines, each with a distinct set of rules. Team sports obviously rely on more than one athlete to achieve victory while individual endurance sports depend exclusively on the ability of one individual to push forward. When it comes to pain, a review by Tesarz et al. (2012) demonstrated that athletes do differ from their non-athlete counterparts. The review confirmed the anecdotal evidence that sport performance resulted in modified pain perception but did not go as far as differentiating the athletes between them.

Specificity of contact sport athletes

Contact sports are defined as any sport that requires contact with opponents. This can include both team sports such as rugby (Tavares et al., 2017) and combat sports (Downey, 2007). In both cases, athletes voluntarily face unpredictable mechanical pain during which they must maintain athletic performance (Thornton et al., 2021) despite pain being a clear obstacle for motor tasks in the general population (Brewer et al., 1990). Looking back to the 60s, a few initial findings that contact sport athletes downplayed painful stimulation when compared to non-athletes served as a foundation for understanding how pain perception is affected by sport participation (Ryan & Foster, 1967). Their methodology involved pressing the spikes of an athletic cleat to the tibia of their participants, a manner for pain induction not currently recognised as valid, but they produced preliminary results nonetheless (Ryan & Foster, 1967). Using more recently validated methods of pain induction i.e., thermal, and ischemic, it was found that a group of contact sport athletes (American football, boxing and wrestling) differed in pain perception when compared to non-contact athletes and non-athletes (Ryan & Kovacic, 1966). For mechanical pain induction, the cleat method was also used, producing similar results (Ryan & Kovacic, 1966). An insignificant difference in pain threshold (heat apparatus) was found in the groups, but they focused on their finding that a considerable difference existed in tolerance (mechanical and ischemic apparatuses) (Ryan & Kovacic, 1966). The contact sport athletes tolerated more pain than non-contact who in turn tolerated more than non-athletes (Ryan & Kovacic, 1966).

More recent work has also examined the differences in pain perception in contact sport athletes with added precision that helps to understand the ways in which these differences manifest. A cold pressor test revealed that a large sample of combat sport athletes (boxing, MMA, karate) had similar pain thresholds to the non-athlete active control group (Leznicka, Pawlak, et al., 2017). They however differed when it came to pain tolerance, this being significantly higher (Leznicka, Pawlak, et al., 2017). The study also took measurements of blood pressure and heart rate where they found that combat sport athletes differed only in that they showed increased systolic blood pressure at test onset (Leznicka, Pawlak, et al., 2017). This was explained as possibly being evidence for increased excitability when faced with pain (Leznicka, Pawlak, et al., 2017). It may also be an indicator of oncoming pain being perceived as a challenge rather than a threat which has been shown to affect cardiovascular response as well as being a trait found in athletes (Jones et al., 2009). Given that Kickboxers self-identify mental toughness as a key psychological contributor to success, a challenge rather than threat state is plausible when it comes to facing experimental pain (Devonport, 2006).

Another cold pressor test study involved both a motor and cognitive task (Sheffield et al., 2020). As previously mentioned, contact sport athletes fared better on the motor task asking them to accurately throw a tennis ball at specific targets than both non-contact athletes and non-athletes (Sheffield et al., 2020). Interestingly, pain was a barrier for all of the groups in the cognitive task which required participants to find and tick off numbers arranged randomly on a grid in order (Sheffield et al., 2020). This is an important addition to understanding how contact sport athletes are affected by pain in an athletic performance setting. It suggests the possibility that attention can be diverted from pain to accomplish a motor task, but not a cognitive task (Sheffield et al., 2020).

These results bring up a line of questioning on causality. In chronic pain research, certain personality traits such as harm avoidance are tied to worse pain outcomes (Naylor et al., 2017). A pain seeking personality is then plausible and may consequently be attracted to contact sport. Taekwondo athletes, for example, display low degrees of pain catastrophising, and employ coping strategies to better deal with the pain they face (Ortenburger et al., 2016). This would imply a certain predisposition to gravitate towards contact sports. The longitudinal study previously mentioned explored how pain tolerance evolves with participation in contact sports (Thornton et al., 2017). Athletes signed up at the beginner level in martial arts, rugby and American football were tested on their pain tolerance after 4 month and 8 months of training (Thornton et al., 2017). They showed that those who stayed had higher tolerance to pain and cope better than those who disengage (Thornton et al., 2017). The results suggest that pain tolerance can be learned through practice and is not an ingrained biological advantage. It is however possible that personality traits or other psychological factors were the cause of dropouts and not their inability to habituate. The possibility of a psychological and biological interaction explaining success in participation in contact sport must then be considered.

Specificity of endurance sport athletes

An athlete's experience with pain exists well before any incidence of injury and is intrinsically tied to performance (Deroche et al., 2011). Endurance athletes anecdotally seem to feel no pain during long bouts of consistent exercise that appear near impossible to the uninitiated. For this reason, Janal et al. (1994a) wanted to explore their impression that runners were more "stoical" than their non-athletic counterparts. They used three of the previously mentioned pain induction methods, namely, the cold pressor test, cutaneous heat, and tourniquet ischemic pain tests (Janal et al., 1994a). Surprisingly, they found that the runners showed a higher tolerance to cold only (Janal et al., 1994a). The authors did not, however, control for exposure to cold baths.

Exploration into the topic did not stop there. Thermal pain (heat and cold) administered to triathletes and non-athletes in a 2013 study confirmed the conclusion of the review written the previous year (Geva & Defrin, 2013). The triathletes had higher pain tolerance in both experimental conditions (Geva & Defrin, 2013). In this example, pain is a monolith and the type of pain induced was not necessarily chosen to match the rigours of triathlon training, but it could be argued that long bouts of endurance training outdoors would condition these athletes to thermal extremes. Interestingly, they also found that on psychometric tests (Fear of Pain and Pain Catastrophising Scale) the triathletes fared better, reporting lower scores on both (Geva & Defrin, 2013). In a later study of triathletes, however, these personality traits did not seem protective when put through acute psychological stress (Geva et al., 2017). The triathletes who had previously demonstrated a decreased sensitivity to pain suddenly lost their advantage over non-athletes (Geva et al., 2017). This continues to emphasise the importance of psychology in the subjectivity of pain perception as much through personality traits as temporary mental states. Recently, endurance athletes pitted their pain perception against that of strength athletes, the argument being that short bouts of extreme effort represented a different enough pain profile from prolonged aerobic activity (Assa et al., 2019). Again, they found that the athletes fared better in their response to pain than non-athletes (Assa et al., 2019). Interestingly, they did find that the type of sport mattered (Assa et al., 2019). The endurance athletes had improved pain inhibition and lower fear of pain whereas the strength athletes had lower pain sensitivity (Assa et al., 2019). These results justify the need for continued testing aimed at identifying the ways in which the type of sport practiced can change pain perception.

4. Objectives of the scoping review

This literature review explored pain through a biopsychological approach and detailed the variety of methods used to induce and measure it in a laboratory setting. In its final section, it provided an overview of the place pain has in sports, namely, the different ways pain is experienced in contact sport athletes when compared to endurance athletes.

Pain was shown to have both a neurobiological pathway in the form of afferent nociceptive fibers traveling to the central nervous system to signal a state of alarm and an important psychological component. The interaction of the two adds nuance to the overall perception of pain and therefore creates a highly subjective experience.

The literature review also compiled the ways that pain can be induced experimentally. Though many methods are available, few approximate pain in sports whether within the muscle during prolonged exercise or due to blows received from an opponent. Thornton et al. (2021) eloquently emphasized the limitation of experimental pain, especially when studying contact sport. They specifically chose the pain pressure test for this exact reason, but the deliberate selection was not made by all who study the topic.

The review finally provided evidence to support those differences in pain perception can be hypothesized to exist between sports and not just between athletes and non-athletes. Given the conclusion that pain induction technique specificity may be crucial to the proper study of the topic, my initial experiment intended to use a cycling task to compare naturally occurring muscle pain during exercise in contact sport athletes and endurance athletes. Due to the COVID-19 pandemic and associated health restrictions, I have conducted a scoping review. This scoping review aimed at mapping the existing literature on pain perception in contact sport athletes. Specifically, this scoping review aimed at answering three questions:

1. What types of sports are being included when studying contact sports?
2. Who are they being compared to?
3. What methods are being used to test pain perception?

The necessity for a scoping review examining the extent of the literature on pain perception differences in athletes according to sport expertise is justified. The heterogeneity of both type of contact sport participants as well as method of pain induction suggest the need for clear recommendations on standards in further research. In addition, athletes representing control groups should be scrutinized to better understand how directed training in an athletic condition is linked to pain perception variance.

Chapter 2 – Scoping Review

This scoping review will be submitted in the journal of Sports Medicine.

Pain Perception in Contact Sport Athletes: A Scoping Review

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ABSTRACT

The present scoping review aimed at exploring the literature surrounding pain perception in contact sport athletes to compile and understand the ways in which it is studied. We hypothesised that there is heterogeneity in the types of athletes being studied, the groups they are being compared to, and the methods used to experimentally induce pain. A database search included articles where contact sport athletes were tested on their pain perception no matter the parameters chosen to do so. Both French and English articles were kept, and no limit was imposed with respect to the year of publication. It was found that a mix of team contact sports and combat sports are studied and included under the umbrella of contact sports. These athletes are being compared to non-athletes as well as athletes from non-contact disciplines. Three methods are predominantly used to study pain in these individuals with a clear preference for the cold pressor test and the pain pressure test. From this review we first conclude that there is a need to clearly define sports based on contact levels expected in play to better define the types of pain athletes are subjected to in their practice. An athlete's level of play as well as years of experience should also be more rigorously noted. Contact sport athletes do in fact seem to have a higher level of pain tolerance than both active controls and non-contact athletes. Methods of pain testing are not always justified. A choice should be made keeping in mind the type of pain specific to the sports being studied. Finally, the scoping review revealed an important diversity in the methods used to induce pain as well as a lack of justification for the choice of these methods. Future experimental studies should use pain testing methods relevant to the pain experience during contact sports and better justify the rationale for the choice of these methods.

1. INTRODUCTION

Pain is "an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage" (Raja et al., 2020) and serves as an alarm for avoiding such damage. The primary purpose of that warning in sport is to caution against possible injury or overwork (Deroche et al., 2011). Sport practice can however encourage athletes to push past those signals in pursuit of performance goals (Deroche et al., 2011). Athletes' motor control and endurance can be hindered by pain, making it an important component of training or competition outcomes (Canestri et al., 2021; Mauger, 2014). It therefore stands that the relationship between athletes and pain is complex.

Not all painful stimuli encountered by athletes are the same. Pain can develop naturally in the muscle with repeated or continuous contraction (O'Connor & Cook, 2001), a sensation often alluded to with training slogans. This exercise-induced muscle pain, also referred as naturally occurring muscle pain during exercise (O'Connor & Cook, 2001), is likely caused by a combination of increased internal pressure, tissue deformation during contraction and the accumulation of noxious metabolites (O'Connor & Cook, 1999). Nociceptors (afferent type III and IV fibers or C and Aδ respectively) respond differently to these stimuli with a subset of type IV responding preferentially to muscle contraction under ischaemic conditions, and both fiber types responding to metabolites (O'Connor & Cook, 1999). Those in a sport where contact is encouraged or required, however, face the additional challenge of having to endure harm purposely done to them by other players. This can represent an additional external mechanical stimulus and would trigger pain pathways associated with skin and muscle deformation rather than those originating naturally in the muscle during exercise. The combination of experience results in the overall perception of pain (O'Connor & Cook, 1999).

Pain exists on a spectrum which emerges just after a stimulus increases in intensity from "unpleasantness" and can be investigated as pain threshold as well as pain tolerance (Loeser & Treede, 2008). The pain threshold is widely defined as the point at which that unpleasant sensation becomes painful to the participant, and pain tolerance is the point at which the pain becomes unbearable (Loeser & Treede, 2008). Pain threshold and pain tolerance can be investigated via different ways of inducing pain experimentally. The Pain Pressure Test, for instance, relies on increasing mechanical pressure applied externally over a body part (Thornton et al., 2021). Thermal pain can be induced in two ways, either by using a cold or warm temperature. The Cold Pressor Test requires that the participant immerse a limb in cold water until they are no longer able to withstand the pain (Raudenbush et al., 2012). Alternatively, heat application can be used in a similar way (O'Connor & Cook, 1999). Mild electric shock can also topically induce pain (O'Connor & Cook, 1999). On top of external methods applied on the skin, several options are available to induce pain within muscles. This can be induced by the application of topical stimuli or injection within the muscles known to stimulate muscle nociceptors or by the completion of physical exercise. In the context of the application of external stimuli, muscle ischemia involves starving the muscle of blood flow using a cuff (Moore et al., 1979). This method will stimulate the muscle nociceptors by trapping the metabolites within the muscles as well as by the application of mechanical pressure on the skin and the muscle where the cuff is located. A more invasive method consists in the injection of noxious chemicals such as hypertonic saline or a mix of exercise-produced metabolites within a muscle to simulate claudication (O'Connor & Cook, 1999) as well as metabolite buildup (Pollak et al., 2014). In the context of muscle pain induced by physical exercise, naturally occurring muscle pain (Cook et al., 1997) and delayed onset muscle soreness (DOMS) are two methods used for the investigation of pain. Delayed onset muscle soreness (DOMS) can be induced through exercise, causing muscle damage to create a painful condition that peaks 48h after completion (Zimmermann et al., 2012). Naturally occurring muscle pain during exercise occurs during aerobic exercise at an intensity and duration that creates an accumulation of metabolites within the muscles known to stimulate the nociceptors, such as bradykinin or H+ (O'Connor & Cook, 2001).

As athletes progress in training and experience, they seem to be able to tolerate more pain than their non-trained counterparts. A review by Tesarz et al. (2012) looked at different measurements of pain comparing athletes to non-athletes and found that overall, athletes have a higher pain tolerance than normally active controls. They did not, however, make a distinction between different types of athletes in accordance with the nature of pain of their sport (e.g., endurance vs contact sport). Contact sport athletes differ from others in that they must accept opponents making physical contact with them as part of engagement in the game. Team sports that fall under that category, such as rugby, have certain rules against excessive physical harm, but some roughness is to be expected, and can in fact be encouraged (Tavares et al., 2017). Combat sports not only have this expectation but require violent, pain-inducing actions to win (Downey, 2007). These sports predominantly face pain resulting from mechanical stimuli due to the shock and action experienced during sport practice. It is therefore likely possible that the pain experienced by contact sport athletes is different that the pain experienced by non-contact sport athletes, such as endurance athletes, who are predominantly facing pain induced by metabolic stimuli resulting from muscle contraction induced metabolic accumulation within the muscle milieu. In this context, studying pain in contact sport as separate is necessary given the difference in pain profiles with other types of sport.

The aim of this scoping review was to explore whether contact sport athletes perceive pain differently, paving the way to explore whether natural ability or specific athletic training can influence pain processing. It explored the ways in which pain experienced during contact sport is researched through three routes of inquiry. First, it asked what sports are being studied as well as the expertise level of the athletes. Second, alongside the athletes in question, the types of control groups being used were also examined. Finally, methodology used to induce pain was scrutinized. While some methods of inducing pain may be more practical, or accessible in a laboratory-controlled environment, not all may be appropriate when testing people with specific sport training if the goal is to generalise to the sport experience.

2. METHODS:

Following the Joanna Briggs Institute (2020) guide for scoping reviews, a protocol was established. Eleven studies were retained out of 699 total search results (see figure 4 for selection process flowchart).

Search Strategy

A librarian (DA) captained the database searches based on those used by Tesarz et al. (2012), in collaboration with AOF. The search strategy consisted of using index terms and keywords in Medline, EMBASE, Sport-Discus, Web of Science, PsycINFO, CINAHL and ProQuest Dissertations & Theses Global search engines. The terms “contact sport”, and “pain” were initially used to parse out studies where pain testing was done with the athletes of interest. The detailed equation search for each data base is available in Supplementary Material. The search in the data base was performed on the 26th of April 2021. Covidence software (Veritas Health Innovation) was used to perform article screening in three steps: removing some duplicates, titles and abstracts, and full texts. Two researchers (AOF and WS) agreed on inclusion at each step of the article screening. In the event of a disagreement, a discussion with a third researcher (BP) determined final inclusion. The initial literature search revealed 699 potential studies of interest, and the screening process led to the inclusion of 9 articles. From later exploration of the “cited by” feature of Google Scholar, a tenth and eleventh relevant article were identified and included. A detailed flowchart of the inclusion process is available in Figure 4.

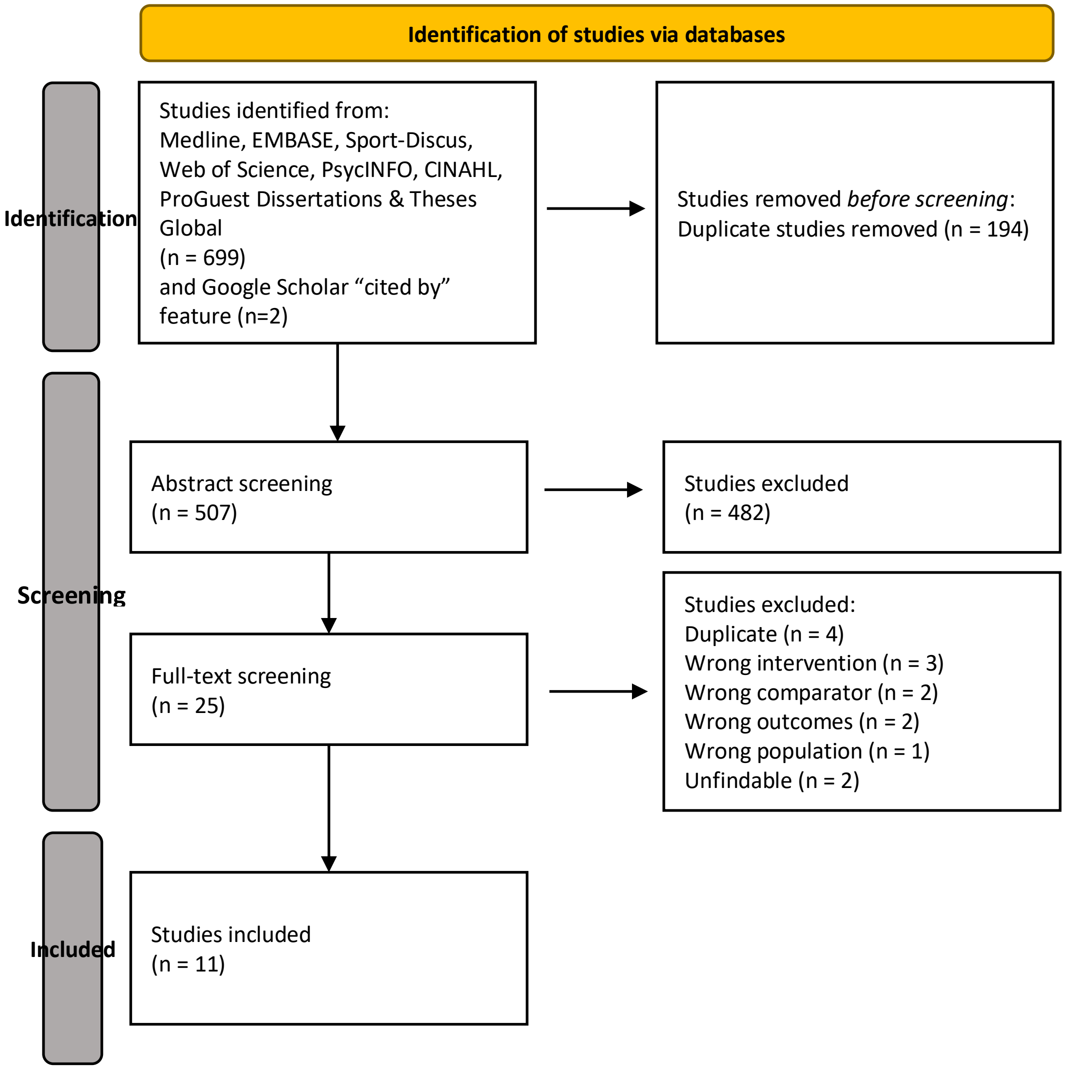

Figure 4: Flowchart of sources screened and included in present scoping review

Inclusion criteria

Publications in both French and English were included regardless of publication year. Inclusion of contact sport athletes were the first criteria. Contact sports are defined as any sport where contact with opponents is necessary for play (Oxford University Press, n.d.) and as such were determined to include combat sports and team sports such as American football, lacrosse, rugby, roller derby, and hurling. Any additional sport was judged based on whether contact between players is encouraged or is considered part of the game. For example, contact is part of soccer, but not encouraged as a tactical play method. Martial artists were included if their practice involved physical contact, therefore excluding meditative arts such as tai chi. Controls were either athletes in non-contact disciplines such as tennis, or non-specifically active individuals.

Included studies had to measure pain threshold, tolerance, both, or a continuum from one to the other. Comparing pain perception can be done primarily using two different parameters, pain threshold and pain tolerance. Pain threshold is the minimal stimulus necessary perceived by a subject as painful. Tolerance is the upper limit of painful stimulus that a subject is willing or capable of enduring. Both were analysed to get a better understanding of pain as a multifaceted sensory experience. In some cases, a visual analog scale was used to monitor the pain intensity from the threshold to the point of maximum tolerance. Methods of pain testing had to be validated to be included and so studies using pain pressure test, cold pressor test, electric shock, heat pain, delayed onset muscle soreness, naturally occurring muscle pain during exercise, and ischaemic pain were retained.

To answer research questions, articles with an experimental pain induction protocol were included as well as reviews including such articles. No reviews detailing pain perception in contact sport were found.

Data extraction

Three authors (AOF, BP, WS) created a data extraction table. A first draft of the table was built by AOF and reviewed by BP and WS. This first data extraction table was then tested by AOF and WS with two articles. Few disagreements were observed, and the three authors updated the data extraction table consequently to obtain the final version available in Supplementary material 2. Data extraction was subsequently performed by AOF and WS, and standardization of the information presented in the table was performed by AOF, BP and WS. Briefly, for the nine included articles, the following information was obtained: reference of the article, details of the contact sport and control group, pain tests performed, and other pain-related measurements collected.

3. RESULTS:

Studies included

Eleven articles were retained for data extraction from the initial 699, all from peer-reviewed journals. To the best of our knowledge, no review focusing on pain in contact has been written. Despite searching articles in French and English, all articles retained were in English. Included articles originated from the USA (n = 4), the UK (n = 3), and Poland (n = 4). Two authors from the UK appeared in all three UK based papers, another author appeared in two. Among the polish teams, the same first author appears in three of four papers. This fact highlights how few researchers are currently working on pain in contact sports. Both articles written in the 60s were first authored by the same researcher.

Timeline of studies examining pain perception in contact sport

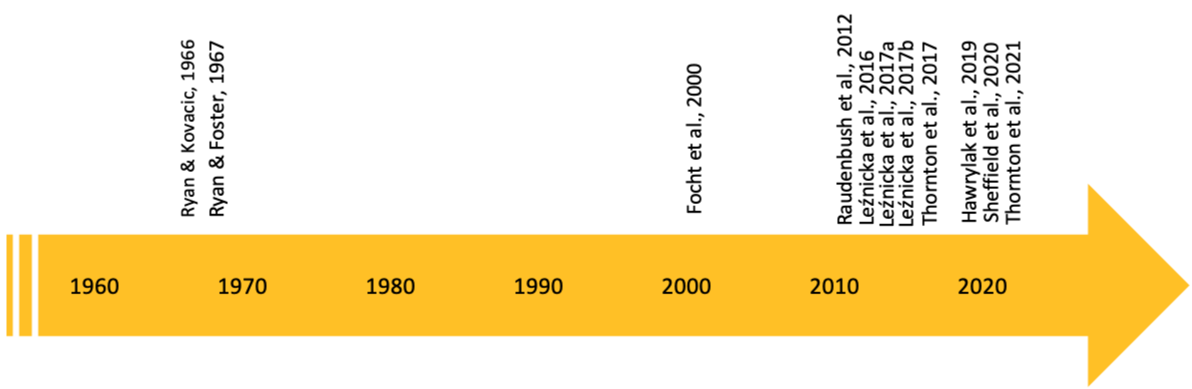

Figure 5: Timeline of studies examining pain perception in contact sport from the 1960s to 2021

Pain perception in contact sports was first studied in the late 1960s. Literature contributing to the topic then ceased being produced until the year 2000 only to ramp up after 2010. The relative density of contributing articles has increased in recent years with eight articles being published in the last ten years.

Types of contact sport being studied

Reviewed studies recruited athletes from 12 sports (Figure 6). In only two cases (Focht et al., 2000; Hawrylak et al., 2019) did the study draw from a single sport, those being karate and judo, rather than recruit from multiple disciplines. Six studies examined team contact sport and nine included combat sports. All individual sports were combat sports.

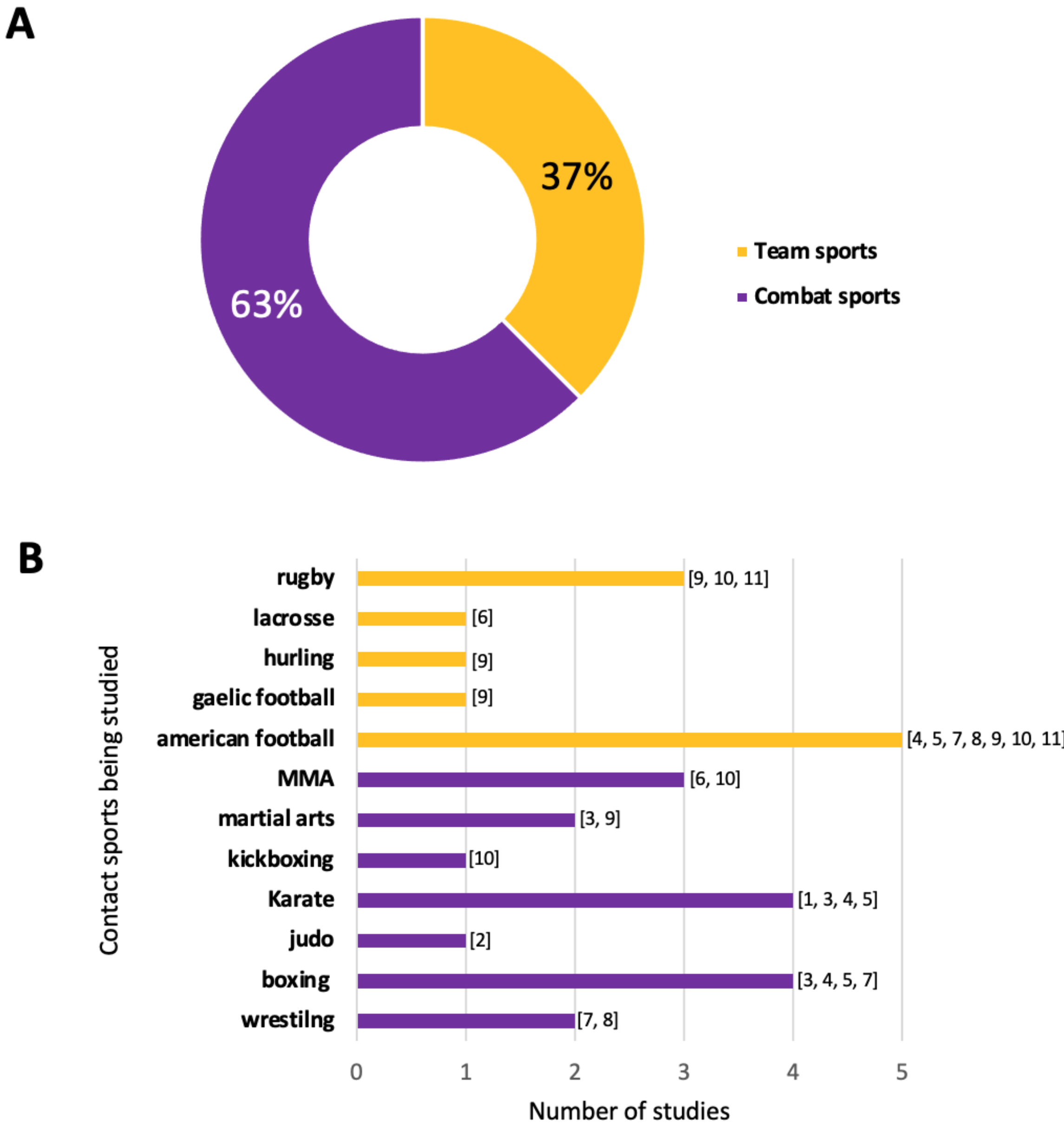

Figure 6. Overview of the contact sports studied. Panel A presents the distribution of combat sports and team sports being studied. Panel B details each specific sport. The numbering in panel B represents each study as follows: [1] Focht et al., 2000; [2] Hawrylak et al., 2019; [3] Leźnicka et al., 2016; [4] Leźnicka et al., 2017a; [5] Leźnicka et al., 2017b; [6] Raudenbush et al., 2012; [7] Ryan & Kovacic, 1966; [8] Ryan & Foster, 1967; [9] Sheffield et al., 2020; [10] Thornton et al., 2017; [11] Thornton et al., 2021. MMA = Mixed Martial Arts.

Groups being compared to contact sport athletes

Contact sport athletes were compared to either untrained individuals or fellow athletes trained in non-contact sports (Figure 7). When untrained or non-athletes represented the control group, general levels of physical activity were unclear. In the case of Leźnicka et al (2017; 2016; 2017) the control group was identified as students from the “Physical Culture” department of the university, and no additional information was offered to determine if these students were otherwise active or inactive despite being classified as untrained individuals. In the case of Hawrylak et al (2019) students were also used as a control group, but in a similar fashion, no precision was given about level of physical activity. Sheffield et al. (2020) has both types of controls, trained individuals, and untrained individuals. Trained individuals were picked from netball, volleyball, soccer, basketball, track, swimming, and cricket. In no case was a distinction made for low contact team sports such as basketball differing from no contact individual sports such as swimming.

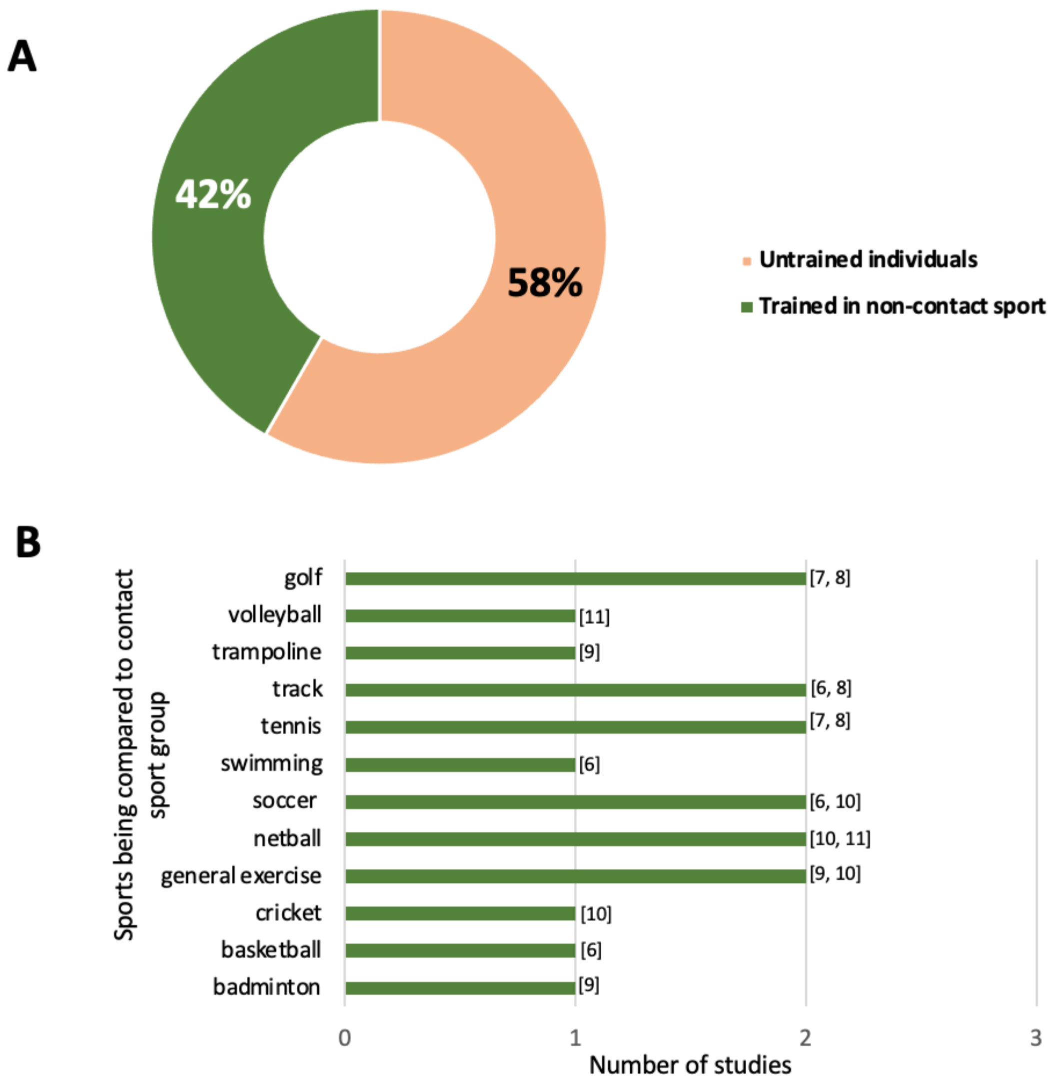

Figure 7. Overview of groups being compared to contact sport athletes. Panel A presents the distribution of untrained individuals as compared to individuals trained in non-contact sport. Panel B details the specific sports practiced by the trained individuals. Numbering in panel B represents each study as follows: Types of non-contact sport being studied and number of studies; [6] Raudenbush et al., 2012; [7] Ryan & Kovacic, 1966; [8] Ryan & Foster, 1967; [9] Sheffield et al., 2020; [10] Thornton et al., 2017; [11] Thornton et al., 2021.

Methods of pain testing

Figure 8 represents the methods of pain testing used in the studies included in the scoping review. Of all available methods of pain testing, four are used across the 11 studies selected: The Pain Pressure Test (Table 1), Cold Pressor Test (Table 2), muscle ischemia (Table 3), and thermal pain through heat (Table 4). Two studies used ischaemic pain (Ryan & Kovacic, 1966; Thornton et al., 2017) and it was paired with other methods. Heat pain was used once in the earliest published article (Ryan & Kovacic, 1966).

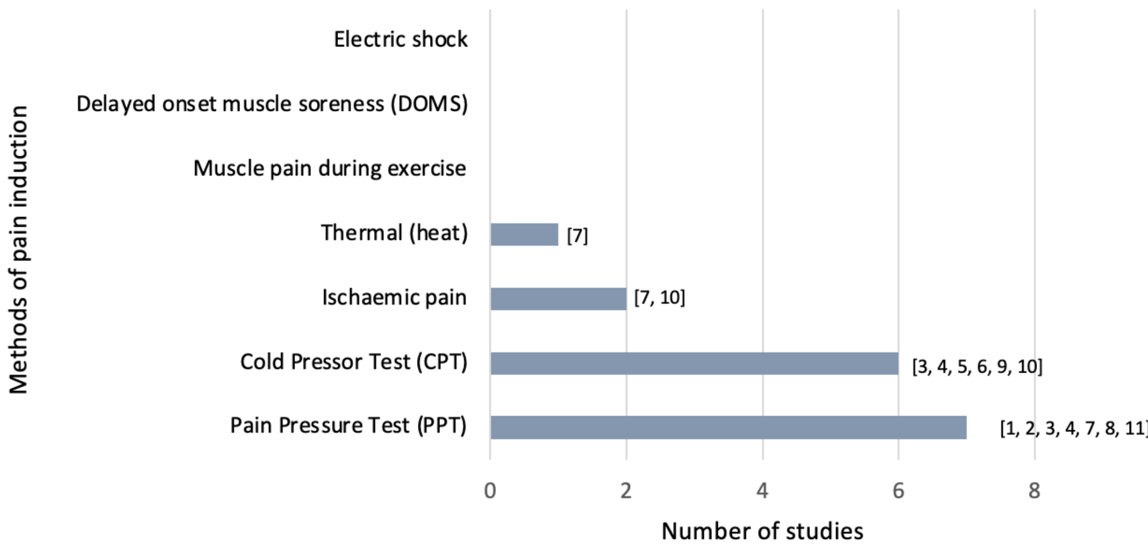

Figure 8: Methods of experimental pain induction, numbering represents each study as follows: [1] Focht et al., 2000; [2] Hawrylak et al., 2019; [3] Leźnicka et al., 2016; [4] Leźnicka et al., 2017a; [5] Leźnicka et al., 2017b; [6] Raudenbush et al., 2012; [7] Ryan & Kovacic, 1966; [8] Ryan & Foster, 1967; [9] Sheffield et al., 2020; [10] Thornton et al., 2017; [11] Thornton et al., 2021.

Main outcomes as reported by study's author – Pain testing

Outcomes measured	*Populations of contact sport included*	*Populations included in control group for comparison*	*Results*
Threshold	Combat sport [1, 2, 3, 4]	Non-athletes [1, 2, 3, 4]	Higher pain threshold in contact sport athletes
Tolerance	Team sport [7, 8, 11] Combat sport [3, 4, 7, 8]	Non-athletes [3, 4, 7, 8, 11] Non-contact athletes [7, 8, 11]	Higher pain tolerance in contact sport athletes
Intensity	Team sport [11] Combat sport [1]	Non-athletes [1] Non-contact athletes [11]	Contact sport athletes perceive pain as less intense Decrease in intensity ratings after contact sport training

Table 1: Studies that used the Pain Pressure Test, outcomes measured, populations included and results; [1] Focht et al., 2000; [2] Hawrylak et al., 2019; [3] Leźnicka et al., 2016; [4] Leźnicka et al., 2017a; [7] Ryan & Kovacic, 1966; [8] Ryan & Foster, 1967; [11] Thornton et al., 2021.

In the case of pain caused by the Pain Pressure Test, all studies showed decreased pain perception as reported by contact sport athletes. This is apparent in four studies that showed increased pain threshold, three studies that showed increased pain tolerance, and two studies that showed differences in pain intensity perception.

Outcomes measured	*Populations of contact sport included*	*Populations included in control group for comparison*	*Results*
Threshold	Team sport [6] Combat sport [3, 4, 5]	Non-athletes [3, 4, 5] Non-contact athletes [6]	Similar pain threshold to control
Tolerance	Team sport [6, 10] Combat sport [3, 4, 5, 10]	Non-athletes [3, 4, 5, 10] Non-contact athletes [6, 10]	Higher pain tolerance than control group
Intensity	Team sport [9] Combat sport [9]	Non-athletes [9] Non-contact athletes [9]	Contact sport athletes signaled lower pain intensity ratings than controls

Table 2. Studies that used the Cold Pressor Test, outcomes measured, populations included and results; [3] Leźnicka et al., 2016; [4] Leźnicka et al., 2017a; [9] Sheffield et al., 2020; [10] Thornton et al., 2017.

When studies used the CPT, a difference can be seen in pain thresholds. Contact sport athletes, while having similar results in pain tolerance to the PPT, seem to have a similar threshold to cold pain than their counterparts.

Outcomes measured	*Populations of contact sport included*	*Populations included in control group for comparison*	*Results*
Tolerance	Team sport [7, 10] Combat sport [7, 10]	Non-athletes [7, 10] Non-contact athletes [7, 10]	Higher pain tolerance than control group with a wider gap between groups after experience gain [10] Higher pain tolerance in contact sport group than non-contact sport group. Higher tolerance in non-contact sport group than non-athletes [7]

Table 3: Studies that used ischaemic pain, outcomes measured, populations included and results; [7] Ryan & Kovacic, 1966; [10] Thornton et al., 2017**.**

An ischemic pain testing protocol found that contact sport athletes both started out with higher pain tolerance than their counterparts, but that the difference in tolerance increased over time and with added experience (here over a period of 8 months) (Thornton et al., 2017). Additionally, contact sport athletes showed a higher tolerance than non-contact athletes who in turn showed better tolerance than non-athletes (Ryan & Kovacic, 1966).

Outcomes measured	Populations of contact sport included	Populations included in control group for comparison	Results
Threshold	Team sport Combat sport	Non-athletes Non-contact athletes	No significance in heat pain threshold between contact sport athletes, non-contact sport athletes and non-athletes

Table 4: Studies that used thermal pain (heat), outcomes measured, populations included and results; Ryan & Kovacic, 1966.

The one study that used heat as a method of pain induction used it exclusively to determine threshold as it was noted that beyond a certain point there is no perceptible increase in pain (Ryan & Kovacic, 1966).

Motor and cognitive performance in presence of experimentally induced pain

Motor performance tests (Sheffield et al., 2020; Thornton et al., 2021) were performed simultaneously with the pain condition in two studies. In both cases, the task required participants to throw a tennis ball at numbered targets in a given order. They were graded based on their accuracy and speed in completing the task. In Sheffield et al. (2020), two conditions were used. In one, the participants had ten targets that they had to hit in numerical order, moving on to the next number regardless of whether they hit the target or not. In the more difficult condition, ten additional targets were added that displayed letters or symbols that had to be disregarded. In Thornton et al. (2021), 20 targets were given, and participants were required to hit the one indicated by researchers immediately before the attempt. A total of ten targets were given, and as with Sheffield et al. (2020), the participant moved on regardless of having hit the target or not. The grading was also based off time and accuracy.

In both studies contact sport athletes differed from control groups. In Sheffield et al. (2020), high contact athletes' motor performance (both in time and accuracy) was not altered by the pain condition while the low-contact athletes and non-athletes performed significantly worse the presence of pain. In Thornton et al. (2021), experienced contact sport athletes not only maintained their motor performance in the pain condition but hit the targets faster than in the non-pain condition. Novice contact athletes maintained their performance in both speed and accuracy. Non-contact athletes performed significantly worse in both testing parameters when in the pain condition.

Sheffield et al. (2020) also had participants perform a cognitive task in both a pain and non-pain condition. The task required participants to check off numbers appearing randomly on a grid in the correct order using pen and paper. The grid contained the numbers one to twenty-five in a random order. Performance was assessed using the time taken to complete the task. Difficulty was added by adding 25 additional numbers that were to be ignored. The pain condition did not alter the performance of the groups regardless of sport expertise.

4. DISCUSSION

This scoping review presents an overview of the literature on pain perception in contact sports. It identifies the types of sports being considered when studying contact sports, the groups they are being compared to, and the various methods used to study pain in those populations. Eleven studies were included, and the literature search did not reveal any reviews focusing on contact sports. The main outcomes of this scoping review were i) an assortment of contact sports was considered across team sports and combat sports; ii) these groups were compared to both non-athletes and non-contact sport athletes; iii) of all available pain testing methods, four were used, with two of them not linked to the pain experienced by contact sport athletes in their practice.

What contact sports are being studied?

The first research question sought to determine which contact sports were being studied. A mix of team sport and combat sport are represented. In two articles, (Leźnicka et al., 2016; Sheffield et al., 2020) the list of participants' sport affiliations includes "martial arts" with no additional information on the type, expertise level, or contact expected in the practice. As an example, tai chi is a martial art that could technically fall under that umbrella, but it is a meditative practice where no contact is made as is qigong and capoeira (Webster et al., 2016). Their inclusion as martial arts can therefore be misleading and introduce population heterogeneity when it comes to pain experience. Similarly, the expertise of participants in contact sports athletes is not thoroughly described in all included studies. Specifying the level of expertise of combat sport athletes is crucial as it conditions the existence and/or intensity of the contact during the practise. To illustrate, it is possible to train in karate without contact while still being considered a martial artist and contact sport athlete. This would be the case for a kata specialist, where practice involves precise movement, but no contact with another karateka (Doria et al., 2009).

Another challenge with the contact sport groups is the mix of team and combat sport within the same group. It remains difficult to ensure that the level of expertise is similar across dissimilar gameplay requirements (Sheffield et al., 2020; Thornton et al., 2017).

For example, it is not possible to reliably claim that a certain belt in karate is equivalent to a certain level of American football. Each sport has demands and classifications systems that do not necessarily overlap, and consequently quantity and intensity of contact during sport practise can widely differ between team and combat sports. Therefore, by integrating these observations, it appears crucial that future studies adopt a more precise and thorough description of contact sports athletes by providing clear information on sport type and expertise level. Also, due to the different nature between combat sports and team sports, a distinction should be made when pooling participants from both types. We do however keep in mind that such dissociation between combat and team sports could lead to more difficulties in reaching an important sample size depending on the sports clubs existing around the research group performing the studies.

To whom are contact sport athletes being compared to?

The participants included in control groups across the studies varied in level of physical activity. In all cases, those identified as non-athletes were students, and their level of activity was mainly unclear. This would be important to note since we can refer to Thornton et al. (2017) where pain perception changed over the course of months of exposure to contact sports. The literature also suggests that sport practise could alter pain perception regardless of the practise of contact sport (Flood, Waddington, Thompson, et al., 2017). A thorough description of the history of exposure to contact sport as well as other sports is necessary when comparing pain perception between sport expertise or across physical activity level in future studies.

As previously mentioned, an identification system detailing the level of contact of each sport should exist to properly classify athlete control groups. For instance, in Sheffield et al. (2020), the no contact group was represented by students while the "low-contact group" was comprised of normally active individuals, tennis players, badminton players, and trampolinists. In none of those sports is contact either required or expected for adequate play. The classification of these sports as "low-contact sports" is confusing as the nature of this sport and their rules does not involve contact. Furthermore, as contact sport involves contact with opponents, these sports could not be considered as low contact as the separation between the opponent with a net refrain any contact with the opponent. It appears more appropriate to classify these sports as no-contact sports, and to classify team sports such as basketball or soccer as low contact sports. Indeed, in these two sports, while contact between opponents is not predominant, the tactical aspects of the sports require few contacts, such as shoulder to shoulder in soccer or performing a pick and roll in basketball. A more rigorous classification of the control group would therefore be beneficial in future research to truly understand how practitioners of different sports can vary in their pain modulation.

What methods of pain testing are being used?

Among the available methods existing to study pain in an experimental setting, four were used in the studies including in this scoping review: pain pressure test, cold pressor test, ischaemic pain, and thermal pain through heat. A clear preference for the use of both the pain pressure test and the cold pressor test exists within the included studies. When studying pain in contact sports, some methods of testing are less appropriate given that they are not normally encountered in training or competition context (e.g., thermal pain, whether heat or cold, is not typically a pain condition of boxing or rugby).

In pain research, certain safeguards are put into place to avoid causing damage to participants. For this reason, the cold pressor test has an upper time limit that a limb can be submerged. This limit is usually not communicated to the participant to avoid creating a target (Leznicka, Starkowska, et al., 2017). This can however limit results when it comes to measuring the tolerance of individuals who frequently experience high levels of pain. An individual in a control group and individual in a contact sport group can therefore both have a maxed-out score despite one being able to continue and the other not. It is a crucial limitation to testing that must be considered in the development of further studies.

The source of pain in combat sport is clear, it is predominately due to contact with the opponent, however, the pain profile of team sports may have another component, naturally occurring muscle pain that comes with prolonged muscle use. Interestingly, none of the included studies considered the investigation of naturally occurring muscle pain during exercise. This would imply that the choice of the type of pain being induced does not take into consideration possible habituation by a contact sport athlete. The expertise, and therefore possible adaptation, provided by training is not cited as a deciding factor. It would therefore be of interest to test this type of pain with other sports to better understand specific pain type modulation required in different sports. For instance, studying naturally occurring muscle pain during exercise in endurance athletes, or further differentiating pain profiles of team contact sports and combat sports. Since each athletic pursuit focuses on different aspects of performance (intensity, time, continuity of movement), the muscle pain involved should have a specific profile based on the sport's parameters.

What are the conclusions of the included studies in pain perception in contact sports?

While our scoping review did not aim to perform a meta-analysis due to the heterogeneity in athletes, control groups and pain testing methods in the literature, it remains possible to discuss the outcomes of these studies as presented by the authors. Specifically, it is possible to discuss differences in pain perception as well as in the effects of pain on cognitive or motor performances. Regarding differences in pain perception, the retained articles measurements of pain threshold, tolerance and intensity were taken using the methods described. When it comes to measuring threshold, all studies tend to align depending on the method of testing. When using mechanical pain, contact sport athletes were reported to have a higher threshold. Studies using cold, however, stated that the pain threshold of all groups were similar. This similarity in pain threshold between the different groups is not intuitively surprising as contact sport athletes are not facing cold pain in their practise, and therefore tolerance to this specific painful stimulus is not developed. This highlights the possibility that the choice of testing method is crucial when studying contact sport athletes, and that sport expertise could develop pain experience differences that are specific to the nature of the sport performed (e.g., no contact sport athletes are regularly facing painful cold, but do face mechanical pain regularly).

Much like Tesarz et al. (2012), athletes were reported as having a higher pain tolerance although here, the distinction of contact sports is added. This applies to all methods of testing. Put together, the results of the retained studies would imply that participation in contact sport goes hand in hand with higher pain tolerance. Further study is obviously necessary.

Pain intensity was reported in three studies (Focht et al., 2000; Sheffield et al., 2020; Thornton et al., 2021). Across the cold pressor test and pain pressure test, it was reported that contact sport athletes signal lower pain intensity ratings throughout testing than their counterparts. Future studies should test this observation with naturally occurring muscle pain during exercise and muscle ischemia, to kind of pain more closely related to sport practise than cold pain.

While cognitive and motor performance in a pain condition was only included in two studies, it would seem like a promising avenue for future research. Maintenance of motor performance in contact sport athletes would imply an ability to modulate pain when faced with a physical task. Cognitively, Sheffield et al. (2020) found that pain did not alter performance and could perhaps be explained by the far more relatable experience of ignoring pain during day-to-day cognitive tasks. Due to the scarce investigation on the effects of pain on cognitive and motor performance in contact sport athletes, future studies are required to be able to conclude on the effects of pain on performance.

Conclusion and perspectives

When testing pain in contact sport athletes, a heterogeneous spread of both team and combat sports are considered. These athletes are compared to both non-athletes, and athletes trained in non-contact sport. Pain perception is predominantly tested using the pain pressure test, the cold pressor test, and with ischaemic pain. Despite naturally occurring muscle pain during exercise being experienced by contact sport athletes, albeit predominantly in team sports, differences between athletes in this specific kind of pain should be considered in future studies.

Further research should consider a more thorough definition of contact sports in opposition to low, or no contact. It should also consider the nature of the pain that sports being tested require athletes to endure to better understand how pain perception can differ in contact sport athletes. Pain threshold and tolerance should be measured given the possibility that one or the other might differ depending on the pain induction technique used. The number of studies examining differences in pain perception in contact sports has increased in the last decade when compared to the first studies in the 60s. It is therefore crucial to adhere to rigorous definitions and justified testing methods to further homogenise the literature. A more rigorous classification of the exact pain profile felt by contact athletes could also help inform the optimal ways to study them. To our knowledge, no method was used to explore pain caused by impact to bone like that caused by shin to shin contact in certain striking sports.

As in Thornton et al. (2017), further longitudinal studies should also be considered to further parse the role of participation in contact sports in pain perception. If a change is indeed attributed to training, then it would imply that it is not natural advantage that allows athletes to excel in their sport despite pain, but rather a developed ability. Such longitudinal studies could highlight the mechanisms associated with the development of pain reduction in contact sport athletes.

Finally, as pain is a perception and results from neurophysiological processes, referred to as nociception in the pain literature, future studies should be interested in differences in nociception between contact sport and other athletes. For example, future studies should investigate differences between sport expertise in nociceptive flexion reflex (R-III) which is considered as an index of spinal nociception (Arsenault et al., 2013). Another direction could be to investigate differences in brain responses to painful stimuli.

Chapter 3 – General Discussion

The aim of this thesis was to extract and analyse the available literature on pain perception in contact sports as well as offer perspectives on considerations in future research into the topic of pain in contact sports. Through observation, it can be supposed that contact sport athletes somehow feel less pain to justify their continued efforts in the face of physical opposition meant to harm. If it is the case that these athletes are somehow more invulnerable, the next logical step is to ask whether they are naturally gifted or if this ability is developed through years of training. The first steps in demystifying the causality are to establish if contact sport athletes differ in their pain perception when compared to individuals not involved in such sports.

The work done on the presented scoping review first allowed for an overview of which sports are being used to study contact sports. This is important given the variety of available disciplines and, with further investigation perhaps allow for a generalisation based off a specific sport rather than a sport category. The review presented these results by splitting contact sports into two subcategories: Team sports and combat sports. These are represented in the literature with 63% of sports being combat and 37% being team sports despite the lack of clear, valid, and standard definitions of contact sports. American football players were recruited for the most studies (n=5), followed by karateka (n=4) and boxers (n=4). Interestingly, one study included both hurling and Gaelic football which were surely choices based on immediate availability. Future studies should aim to further differentiate in combat and team contact sport. The predominance of mechanical pain in combat sport contrasted with a balance of mechanical pain and naturally occurring muscle pain in team sports should warrant additional exploration as two distinct groups.

Evidently, the sensory conditions of all contact sports cannot be equal. Equipment, environmental, or time of play factors perhaps add enough nuance to each sport for a direct comparison of the subjective experience of pain to be void. Furthermore, level of play is difficult to match. No standards exist to clearly state that a certain level of rugby is equivalent, in terms of pain habituation, to a certain belt colour in judo. Despite this, all studies assembled reported similar findings in terms of pain threshold, tolerance, and pain intensity ratings. Relying on the longitudinal study included in the review, experience could be a more critical factor to control for when selecting an experimental group comprised of contact sport athletes than coherence between sports. They showed that adherence to contact sports changed tolerance to ischemic pain over months of practice (Thornton et al., 2017). Unfortunately, hours of practice and details such as how quickly beginners are exposed to contact were not provided. This would allow for a more thorough portrait of the evolution of pain perception. Naturally, going forward it would be interesting to repeat a similar study comparing the progression of athletes from different contact sport disciplines.

The first studies done to compare pain perception in contact sport athletes compared this population to both non-contact athletes and non-athletes (Ryan & Foster, 1967; Ryan & Kovacic, 1966). Subsequent studies did not always include both groups. There are, of course, merits to using either subcategory depending on the objective of each research project. A comparison between contact sport athletes and non-contact athletes could provide important insight as to whether sport specialisation also results in differences in pain perception. Alternatively, a contrasting contact sport athletes with non-athletes can further strengthen the affirmation that athletes are indeed different. Both group comparisons have merit, and an argument could be made that including all three populations would strengthen the affirmation that contact sport athletes do in fact perceive pain in a way that differs from others.

Some studies included in the review used both options for comparison. Ultimately, this meant that untrained individuals represented 58% of comparison groups over included studies i.e., 7 of the control groups were non-athletes. This leaves 5 groups, or 42%, as non-contact athletes. As mentioned, rigorous definitions of contact and non-contact sports do not exist in the literature. These athletes span team sports as well as individual sports. Furthermore, individuals who participate regularly in exercise for fitness were included. This group was included in two studies.

Studies who used non-contact athletes should be considered separate from those who use non-athletes exclusively. The available literature review comparing pain perception in athletes when compared with normally active controls concluded that pain perception was altered in athletes (Tesarz et al., 2012). They separated athletes into “game”, “endurance”, and “strength” sports but did not include contact sports as a distinct option.

The last question posed in the review aimed to determine what methodologies were used to test pain experimentally. Out of all available methods for pain induction, four were used. Studying pain using the best available method can indeed serve to highlight distinctions between groups whose pain experience profiles are unknown or unimportant. When studying athletes, it would be necessary to justify the choice according to the types of pain common to their sport. Once a method is selected, thought must also be put into the available options for the localisation of pain induction. While measuring mechanical pain in a boxer, for example, a pain pressure test would seem an appropriate tool, but a deliberate choice must be made about where the pressure is applied. Compressing a finger might yield different results from compressing a forearm due to differences in nerve ending density and habituation. On top of these physical measures, psychological testing using questionnaires evaluating, for example, personality traits, should be done. This would allow for further understanding of the factors contributing to an athlete playing through pain. conjunction of the psychological and biological aspects of pain are inseparable, and so the inclusion seems necessary.

The results of the included studies were obviously not used in a meta-analysis. For example, rarely were measures of threshold, or tolerance taken in conjunction with intensity ratings. To extrapolate a portrait of pain perception, all three should be included. Authors tended to agree, however, with the results of the measurements taken. For example, all studies who measured pain tolerance using the pain pressure test found that contact sport athletes had a higher pain tolerance (table 1). This was true no matter the control group. Studies who used the cold pressor test to study threshold interestingly found that no difference existed between groups, a fact that isn’t reflected when it came to threshold in the pressure test (table 2). Threshold measurements taken in that case showed that contact sport athletes had a higher threshold. This was only done in one case where the comparison group was comprised of non-athletes. While no general conclusions can be draw from these tables at face value, they hint the possibility that differences in pain perception are reflected differently based on the testing method used and the expertise of the subject.

A pain profile corresponding to different athletic disciplines should be elaborated. This would allow for better testing decisions if the goal is to study how one group fares over another. Triathletes, for example, might intuitively be tested with a cold pressor test, ischemic test, and a test using muscle pain at exercise if they are to be compared to rugby players with a different pain profile. The further detailed studies can get about these differences in expertise, the more can be understood about how sports allow an individual to habituate to certain types of pain if it is in fact a question of change over time. If the other side of the coin is true and that certain athletes, such as those who participate in combat sports, are naturally less sensitive to pain, then further differentiation would allow for activity initiation recommendations to be made to individuals based on their pain profiles.

Perspective experiment for testing naturally occurring muscle pain during exercise in combat and endurance sport athletes

In a laboratory setting, most experimental protocols use external methods of pain induction such as heat, cold or mechanical pressure. The pain response provoked by these methods are however different from naturally occurring muscle pain produced during exercise. The variances in how athletes from different sports perceive this type of muscle pain during aerobic exercise is still unknown. For example, we could expect that an endurance athlete who routinely experiences naturally occurring muscle pain during training would be more accustomed to this specific pain than a contact sport athlete who predominantly faces mechanical pain. In this context, a study aiming to compare the perception of muscle pain produced in the quadriceps during an intense cycling bout between contact sport athletes, endurance athletes, and non-specifically trained individuals would be unique. It would be of interest to improve our knowledge on pain perception in sports. Such a study was the original content of my MSc but had to be cancelled due to the pandemic. I had the opportunity to create the protocol and present it at a conference at the School of Kinesiology. This study is the ideal perspective to conclude my MSc as it directly addresses one of the gaps identified by the scoping review. Therefore, a short abstract of this originally planned experimental study is provided below.

Abstract

In this study, three groups of participants (contact sport athletes, endurance sport athletes, and normally active individuals) will be asked to complete two experimental procedures. In the first session, they will fill out two questionnaires aiming to evaluate their impressions on pain (Fear of Pain and Pain Catastrophising Scale). Next, they will complete an incremental cycling task to determine their maximal aerobic power. During this time, they will quantify the pain intensity felt in the quadriceps, their perception of effort at each increment increase and their affective response. Perceptions of pain and effort will be evaluated using the Borg CR100 scale (Borg & Kaijser, 2006; Pageaux et al., 2020). Affect will be measured using a -5 to +5 feelings scale (Hardy & Rejeski, 1989). In the second session, mechanical pain and naturally occurring muscle pain during exercise will be investigated. First, mechanical pain will be assessed via completion of pain pressure test. Second, naturally occurring muscle pain will be assessed via completion of our cycling blocks of five minutes on a stationary bicycle at 35%, 50%, 65%, and 80% of their maximum aerobic power. According to the previous results of Cook et al. (1997), these relative power outputs correspond to one intensity below the pain threshold (35%), one around the pain threshold (50%) and two above the pain threshold. Pain perception and perception of effort will be evaluated following each block. Ten minutes of rest will be granted between each cycling bout to control for exercise-induced muscle fatigue and to fill out the McGill Pain Questionnaire which will allow participants to qualify and pinpoint their pain. During both sessions, heart rate, respiration rates, and electromyographic activity of the vastus lateralis will be continuously monitored. It is hypothesised that the intensity of naturally occurring muscle pain during exercise will be lower in athletes compared to non-athletes. Furthermore, due to the predominance of this

kind of pain in endurance athletes, it is also hypothesised that the pain intensity will be lower in endurance athletes compared to contact sport athletes.

In conclusion, athletes are faced with varying degrees of pain in their practice. They must learn to perform with the specific types of pain tied to their chosen sport. The scoping review presented the ways in which contact sports are studied and highlights a lack of homogeneity in the literature. The proposed study would help to close one identified gap by using specific athlete types and deliberate testing methods aimed at approximating muscle pain felt during exercise. As several studies included in the review have brought up in their perspectives sections, a future objective would be to determine the causality of differences in pain perception. Are people with high pain tolerance more likely to seek out activities with expected pain, or is the decreased sensitivity developed with training?

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Supplementary Material 1: Database Search

Key concepts in Scoping review database search

Concepts	**Tolérance à la douleur aigue**	**Activités de combat/sports de contact**
Mots-clés	"Tolerance of pain" Pain perception Pain sensitivity Pain threshold Pain tolerance Acute pain Pain pressure test Cold pressor test Electric shock stimulation pain Exercise induced muscle pain Ischaemic pain Ischemic pain	Combat sport* fighting sport* aikido Boxing Fencing jiu jitsu Judo Karate Kickboxing kung fu Martial arts mixed martial arts (MMA) muay thai taekwondo wrestling wushu Contact sport* American/canadian football australian football Hurling Rugby
Bases de données	**Descripteurs**	**Descripteurs**
Medline (Ovid) 1946-	Acute Pain/ pain perception/ or nociception/ Pain Threshold/ Pain Measurement/	boxing/ or football/ or martial arts/ or wrestling/
Embase (Ovid) 1974-	pain parameters/ or pain intensity/ or pain severity/ pain threshold/ or heat pain threshold/ or pressure pain threshold/ nociception/ pain measurement/ pain assessment/	martial art/ or aikido/ or jiu jitsu/ or judo/ or karate/ or kung fu/ or taekwondo/ or "wushu (sport)"/ combat sport/ or boxing/ or "fencing (sport)"/ or kickboxing/ or wrestling/ contact sport/ or collision sport/ football/ or football player/ rugby/ or wheelchair rugby/

PsycInfo (Ovid) 1806-	pain perception/ or pain thresholds/ or acute pain/ or pain measurement/	football/ or judo/ or martial arts/
SportDiscus with Full Text (Ebsco) 1975-	DE "PAIN pressure threshold" OR DE "PAIN measurement" OR DE "PAIN tolerance"	DE "CONTACT sports" DE "DUELING" OR DE "ACADEMIC fencing" OR DE "CLASSICAL fencing" OR DE "FENCING" OR DE "HISTORICAL fencing" OR DE "SCA fencing" OR DE "SPORT fencing" OR DE "HAND-to-hand fighting" OR DE "BOXING" OR DE "FENCING" OR DE "PANCRATIUM" OR DE "STICK fighting" OR DE "WRESTLING" OR DE "COMBAT sports" OR DE "DUELING" OR DE "HAND-to-hand fighting" OR DE "MARTIAL arts" OR DE "STICK fighting" OR DE "KENDO" OR DE "NUNCHAKU" OR DE "QUARTER-staff" OR DE "SINGLE-stick" OR DE "MARTIAL arts" OR DE "BUDO" OR DE "EAST Asian martial arts" OR DE "ESCRIMA" OR DE "JEET Kune Do" OR DE "JU-kenpo" OR DE "KAJUKENBO" OR DE "KALARIPPAYATTU" OR DE "KENJUTSU" OR DE "KENPO" OR DE "KICKBOXING" OR DE "KRAV maga" OR DE "KUN-tao" OR DE "KYUDO (Archery)" OR DE "LION dance" OR DE "MARTIAL arts for children" OR DE "MARTIAL arts for people with disabilities" OR DE "MIXED martial arts" OR DE "NINJUTSU" OR DE "PENCAK silat" OR DE "SAN-jitsu" OR DE "SHISHIMAI (Dance)" OR DE "SPEAR fighting" OR DE "MARTIAL artists" OR DE "NINJA" OR DE "WOMEN martial artists" OR DE "FENCING" OR DE "ACADEMIC fencing" OR DE "CLASSICAL fencing" OR DE "HISTORICAL fencing" OR DE "KENDO" OR DE "SCA fencing" OR DE "SINGLE-stick" OR DE "SPORT fencing" OR DE "WHEELCHAIR fencing" OR DE "WOMEN'S fencing" DE "FOOTBALL" OR DE "AUSTRALIAN football" OR DE "GAELIC football" OR DE "RUGBY football" OR DE "FOOTBALL players" OR DE "CANADIAN football" OR DE "WOMEN'S rugby football" OR DE "WOMEN football players" OR DE "RUGBY Union football players" OR DE "RUGBY League football players" OR DE "PROFESSIONAL football" OR DE "RUGBY football players"

		DE "HURLING (Game)" OR DE "HURLING players"
CINAHL Plus with Full Text (Ebsco) 1937-	(MH "Nociceptive Pain") OR (MH "Pain Measurement") OR (MH "Pain Threshold")	(MH "Contact Sports") OR (MH "Boxing") OR (MH "Football") OR (MH "Martial Arts") OR (MH "Rugby") OR (MH "Wrestling") OR (MH "Fencing")
Web of Science (Clarivate) 1945-	-	-
ProQuest Dissertations & Theses Global	-	-

Search equations

Pain tolerance

OVID
(pain ADJ3 (tolerance OR perception OR sensitivity OR control OR threshold OR acute))
OR
("pain pressure test" OR "pressure pain test" OR "cold pressor test" OR "electric shock stimulation pain" OR "exercise induced muscle pain" OR "isch?emic pain")

EBSCO
(pain N2 (tolerance OR perception OR sensitivity OR control OR threshold OR acute))
OR
("pain pressure test" OR "pressure pain test" OR "cold pressor test" OR "electric shock stimulation pain" OR "exercise induced muscle pain" OR "isch#emic pain")

WOS
(pain NEAR/2 (tolerance OR perception OR sensitivity OR control OR threshold OR acute))
OR "pain pressure test" OR "pressure pain test" OR "cold pressor test" OR "electric shock stimulation pain" OR "exercise induced muscle pain" OR "ischaemic pain" OR "ischemic pain"

Contact sport

OVID
(Sport* ADJ1 (combat OR fighting OR contact))
OR (aikido OR boxing OR fencing OR "jiu jitsu" OR judo OR karate OR kickboxing OR "kung fu" OR "martial arts" OR "mixed martial arts" OR "muay thai" OR taekwondo OR

wrestling OR wushu OR "american football" OR "canadian football" OR "australian football" OR hurling OR rugby)

EBSCO
"combat sport*" OR "fighting sport*" OR "contact sport*" OR aikido OR boxing OR fencing OR "jiu jitsu" OR judo OR karate OR kickboxing OR "kung fu" OR "martial arts" OR "mixed martial arts" OR "muay thai" OR taekwondo OR wrestling OR wushu OR "contact sport*" OR "american football" OR "canadian football" OR "australian football" OR hurling OR rugby

WOS
"combat sport*" OR "fighting sport*" OR "contact sport*" OR aikido OR boxing OR fencing OR "jiu jitsu" OR judo OR karate OR kickboxing OR "kung fu" OR "martial arts" OR "mixed martial arts" OR "muay thai" OR taekwondo OR wrestling OR wushu OR "contact sport*" OR "american football" OR "canadian football" OR "australian football" OR hurling OR rugby

Supplementary Material 2: Data extraction table

Publication	Title		
	Author(s)		
	Year of publication		
	Journal		
Population	Total		
	Age		
	N of contact athletes (f/m)		
	Age		
	Sport (rugby, karate etc.)		
	Years of experience		
	Competitive (N / national / international)		
	N of controls (f/m)		
	Age of controls		
	Athletes (Y \ N)		
	Sport (if applicable)		
	Trained (Y/N)		
	Years of experience		
	Competitive (N/national/ international)		
Main outcomes	Test performed		
	Test parameters (threshold, tolerance, perception)		
	Test results		
	Physiological measurements		
	Outcome measured (threshold, tolerance, pain rating)		
Other pain-related measurements	Motor or cognitive performance in presence of pain (Y \ N)		
	Results		
	Pain questionnaires		
Review Question 1	Answer to review question 1		
	Limit to review question 1		
Review Question 2	Answer to review question 1		
	Limit to review question 1		
Review Question 3	Answer to review question 1		
	Limit to review question 1		